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ORDOVICIAN AND SILURIAN STRATIGRAPHY AND STRUCTURE IN THE WOMBAT CREEK—BENAMBRA AREA, NORTHEAST VICTORIA

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ABSTRACT: Undifferentiated Ordovician low grade metasediments are unconformably overlain by a Silurian succession consisting of the Middle (?) Silurian Mitta Mitta Volcanics and the Late Silurian Wombat Creek Group. The Ordovician beds have undergone several periods of folding, regional metamorphism and granitic intrusion in the Benambran Deformation. Silurian rocks are preserved in a graben which is considered to have been active during deposition. The Wombat Creek Group consists of three newly described formations, in ascending order, the Toaks Creek Conglomerate, Gibbo River Siltstone and Tongaro Sandstone. Facies relationships of these units suggest it is a transgressive sequence with the fluvial(?) to shallow marine Toaks Creek Conglomerate overlain by the shallow marine Gibbo River Siltstone and "deeper" marine Tongaro Sandstone. The Silurian sequence in the Graben correlates with a similar sequence at Limestone Creek (VandenBerg *et al.* in press) and other Silurian sequences in southeastern Australia.

A thick Silurian sequence exposed in the Wombat Creek-Gibbo River area about 20 km north of Benambra is preserved in a structure here named the Wombat Creek Graben. The graben is bounded by the Wombat Creek and Morass Creek Faults and trends northwest-southeast, extending from Soldier Creek to near Taylors Crossing (Fig. 1). There is a small outlier along Morass Creek near Benambra (Fig. 1). The Silurian sequence unconformably overlies multiply deformed Ordovician sandstone, slate and siltstone and consists of the Middle(?) Silurian Mitta Mitta Volcanics and the Upper Silurian Wombat Creek Group.

The Ordovician beds were deformed during the Early(?) Silurian Banambran orogeny of Browne (1947). To the west they grade into high grade regional metamorphic and granitic rocks of the Omeo Metamorphic Complex. The Silurian sequence in the Wombat Creek Graben was tightly folded during the Early Devonian Bindian Deformation (VandenBerg *et al.* in press) and was also intruded by acid to intermediate plutonic rocks. Syenite, trachyte and granite porphyry were emplaced east of Benambra during the Triassic. Cainozoic faulting in the area has resulted in rejuvenation of the mature topography, accompanied by stream diversion and river capture, and in the late Pliocene, the Morass Creek Basalt was extruded north of Benambra.

The purpose of this paper is to define and describe the poorly known Silurian stratigraphy within the Wombat Creek Graben, and to discuss the depositional environments of the sediments and the structural relationships of the Silurian sequence to older rocks.

Map grid references are quoted in the text with the prefix (GR...) and refer to the Benambra 1:100 000 topographic sheet, No 8424, Series R652, Division of National Mapping, Department of National Development.

PREVIOUS WORK

The earliest investigations in the area were made by Stirling (1887, 1888, 1889) and Ferguson (1899) who compiled the first stratigraphic column of the Wombat Creek Group. Dunn (1907a, b) made a brief study of the distribution of ore minerals in limestones of the Wombat Creek Group. Whitelaw mapped the isolated limestone outcrops in detail in 1913, but his work was not published until 1954. Chapman (1906, 1912, 1917, 1920) identified fossils collected from the Wombat Creek Group by earlier workers. While examining possible sites for the location of a dam on the Mitta Mitta River, Kenny (1937) examined the contact between the volcanics and the Wombat Creek Group at the junction of the Gibbo and Mitta Mitta Rivers, and suggested that the volcanics unconformably overlie the sediments.

Andrews (1938) described the stratigraphy and structural relationships of the Silurian and Ordovician and suggested that an intense deformation event, which he named the Mitta Mitta Movement, affected the Ordovician prior to the accumulation of the Silurian sequence. This event was later named the Benambran Orogeny by Browne (1947).

Crohn (1950) gave the name Wombat Creek Formation to the sequence of conglomerate, limestone, sandstone and shale exposed along the Mitta Mitta River. Talent (1959a) upgraded this to group status without defining constituent formations, and suggested a Middle to Late Silurian age, thus inferring an Early Silurian age for the Benambran Orogeny. Beavis (1962) discussed the structure of the Wombat Creek Group in his regional study of the Omeo metamorphic Complex, and Singleton (1965), and Talent (1965, 1969) briefly described the stratigraphy of the Wombat Creek Group and its relationship to the Mitta Mitta Volcanics. Talent *et al.* (1975) discussed the stratigraphy and correlation of the Silurian rocks in the Wombat Creek Graben.

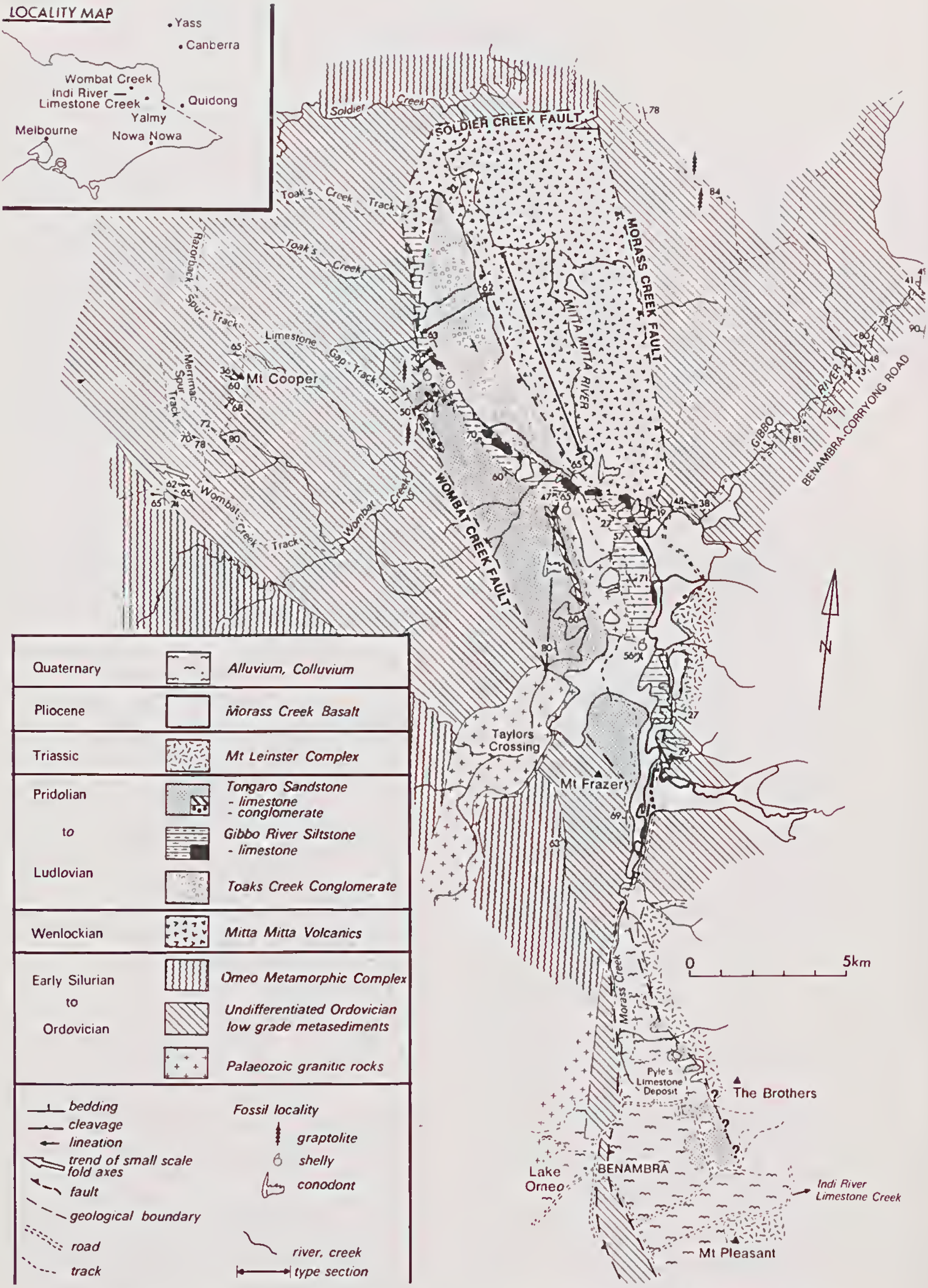


Fig. 1—Geological map of the Wombat Creek—Mitta Mitta River area, Benambra, Victoria.

STRATIGRAPHY

Ordovician

Distribution: Ordovician sedimentary and low grade metasedimentary rocks surround the Wombat Creek Graben and outcrop extensively in eastern Victoria beyond the study area. The Ordovician rocks have been regionally metamorphosed to biotite grade, and pass westwards into higher grade regional metamorphic rocks of the Omeo Metamorphic Complex.

Lithology: The Ordovician sequence in northeastern Victoria comprises an undetermined thickness of well bedded sandstone and mudstone. The beds are steeply dipping and tightly, often isoclinally folded. Slaty cleavage is well developed in many of the finer beds. No attempt has been made to subdivide the Ordovician lithologically.

Grey to yellow coarse to fine sandstone beds up to 1 m thick, are usually graded and sometimes contain internal lamination, convolute lamination and ripple marks. The upper parts of some massive beds display gently undulating bedding. Laminated and thinly bedded grey-green argillites form the upper parts of graded beds. Thin, medium to fine grained sandstones are sometimes graded and often display ripple-drift cross-lamination, planar lamination and ripple marks. The sandstones generally have planar bases with occasional load casts. Sole marks are not commonly observed but this may be due to lack of exposure of the undersides of beds. There are shaly intraclasts in some sandstones. The sandstones are quartz rich (quartzose waekes in the classification of Okada, 1971), with quartz comprising up to 70% of the rock and 95% of the framework. Quartz grains are mostly equant to elongate, angular to subangular, monocrystalline grains with undulose extinction. Weathered feldspars comprise up to 15% of some rocks, but are generally less than 5%. In thin section, alkali feldspar appears to be subordinate to plagioclase (andesine (?) to labradorite). There are occasional biotite plates and muscovite is common. Equigranular and foliated quartzite occurs as uncommon sand sized grains. The matrix, comprising up to 40% of some rocks, consists of clays, muscovite, chlorite, rare biotite and very fine quartz. Platy minerals and some bladed quartz grains are stongly aligned. Massive grey to yellow quartzites up to 2 m thick are usually structureless but occasionally contain internal lamination. They are coarse to fine sandstones composed almost entirely of quartz with rare feldspar, muscovite and heavy minerals. The quartzites have usually been recrystallized with framework grains within a fine grained polycrystalline quartz aggregate. They are often intersected by quartz veins. Finer beds may be cherty. The Ordovician sediments exhibit abundant AE, subordinate AB and ABC, rare BC and interturbidite E divisions of Bouma's (1962) turbidite cycle. No complete A→E Bouma sequences have been recorded.

Discrete units of laminated grey to black slate, more than 20 m thick on the Eustace Gap track, contain poorly preserved graptolites. These units have not been mapped in detail, but they may represent marker horizons within the Ordovician sequence. The slates are composed of varying proportions of silt-sized angular quartz and detrital muscovite, set in a very fine matrix of clays, muscovite, biotite and chlorite. A strongly developed slaty cleavage is due to alignment of platy minerals and some quartz grains. Some very dark grey beds contain abundant carbon and often contain oxidized pyrite cubes.

Age: Graptolites have been found at a number of localities in the Mitta Mitta River area. They are generally poorly preserved and strongly distorted by slaty cleavage. Black slate units within the area contain species including *Climacograptus affinis, C.* cf. *tubuliferus, C. spiniferus, C. bicornis, C. caudatus, Orthograptus* cf. *quadrimucronatus, O.* cf. *amplexicaulis, Dicranograptus ramosus, D. hians, Dicellograptus* sp., and numerous unidentifiable diplograptids (Bolger 1978). These suggest a broad age range of Gisbornian to Eastonian. One rather dubious occurrence of *Phyllograptus nobilis* associated with species of "*Diplograptus*" and "*Climacograptus*" has been recorded from the Gibbo River (Harris & Keble 1932) and suggests a Darriwilian (Da3) age for the Ordovician in this area. More recently Kilpatrick and Fleming (1980) have found early Bendigonian graptolites including *Tetragraptus fruticosus* in knotted schist in the Eskdale area west of the Wombat Creek Graben, indicating that a large part of the Ordovician sequence (so far unfossiliferous) may be of Early Ordovician age.

Silurian

Silurian rocks in the area are confined to the Wombat Creek Graben and comprise a thick sequence of acid volcanics (Mitta Mitta Volcanics) and terrigeneous and carbonate sediments (Wombat Creek Group).

Mitta Mitta Volcanics (Singleton 1965)

Distribution, Thickness and Lithology: The Mitta Mitta Volcanics comprise a suite of dacite and rhyodacite outcropping from the junction of the Mitta Mitta and Gibbo Rivers to near Yankee Point. They form steep bluffs and resistant ridges on both sides of the Mitta Mitta River. The rocks are massive and apart from an outcrop of columnar jointed rhyodacite on the Mitta Mitta River (GR 595327) the volcanics are structureless. They are fine grained, with small phenocrysts of quartz, plagioclase and rare K-feldspar and biotite in a chloritic devitrified groundmass. The sparsity of structural data and lack of younging criteria in the Mitta Mitta Volcanics do not allow an accurate estimation of thickness although the sequence is considered to be at least 500 m thick on the Mitta Mitta River.

Type Section: The best exposures of the Mitta Mitta Volcanics were along the Mitta Mitta River prior to inundation by the Dartmouth Dam, and this would have been the logical type section had flooding not occurred. The only other accessible area of exposure is along the main ridge east of Limestone Gap between the Mitta Mitta River and Toak's Creek Track and this is proposed as the type area for the Mitta Mitta Volcanics (between GR 555388 and 588327).

Relationships: The Mitta Mitta Volcanics are faulted against Ordovician metasediments in complex fault zones near Eustace Gap (GR 585428, 589425) and on the Mitta Mitta River near Yankee Point (GR 538414) where there is a fault zone 100 m wide. Contacts with the Wombat Creek Group are also faulted, with much deformation of the latter at the contact along the Mitta Mitta River (GR 592322). The presence of pebbles of Mitta Mitta Volcanics within the basal conglomerate of the Wombat Creek Group suggest that the Wombat Creek Group post-dates the volcanics.

Age: The Mitta Mitta Volcanics post-date the Ordovician beds and pre-date the Upper Silurian Wombat Creek Group, but a more accurate age determination is not possible. The volcanics are considered on regional grounds to be correlatives of the Thorkidaan Volcanic Group (VandenBerg *et al.* in press) outcropping east of Benambra. Tentative correlation with the Douro Group (Pogson & Baker, 1974) in the Yass area of New South Wales implies a Middle Silurian (Wenlockian) age for the Mitta Mitta Volcanics.

Wombat Creek Group (Crohn 1950)

Distribution, Type Section, Thickness: The Wombat Creek Group comprises three formations: the Toaks Creek Conglomerate, the Gibbo River Siltstone and the Tongaro Sandstone, which all outcrop within the Wombat Creek Graben from the Toaks Creek track southwards to near Mt Frazer. A small outlier along Morass Creek, Benambra, near "The Brothers" contains sediments referred to the Tongaro Sandstone (Fig. 1).

The proposed type section is a composite section comprising three segments (Fig. 1): (i) a section along the Toaks Creek walking track from Toaks Creek (GR 553380) to near Limestone Gap (GR 537363); (ii) the exposures along the Limestone Gap Track from Limestone Gap (GR 542355) to the Wombat Creek Fault (GR 541359); (iii) exposures along Wombat Creek from GR 547342 to GR 541336. The thickness in this composite section is probably in excess of 3800 m (Fig. 2) although this may be an overestimate due to repetition by tight folding.

Relationships and Boundary Criteria: The presence of pebbles of Mitta Mitta Volcanics within conglomerates of the Wombat Creek Group indicates that the sediments post-date the Volcanics although the contact is now a low angle thrust fault. At the contact the Mitta Mitta Volcanics have behaved competently and were little deformed by the faulting, whereas the Wombat Creek Group sediments are faulted, folded and intensely fractured. Along the Gibbo River, the Mitta Mitta Volcanics have been thrust over the Wombat Creek Group to give the false appearance of an unconformity and reversed superposition. The contact with the Mitta Mitta Volcanics along the Toak's Creek track is complexly faulted.

The top of the Wombat Creek Group is faulted against graptolitic Ordovician sediments along the Wombat Creek Fault, which has a crush zone 50 m wide well exposed along the Limestone Gap track (GR 541349). Further south, the boundary with the Ordovician rocks is difficult to locate accurately as the Ordovician beds adjacent to the western edge of the Wombat Creek Graben are often quartz-rich and difficult to distinguish from the Tongaro Sandstone. It is possible that the graptolitic Ordovician shales exposed along the Limestone Gap Track and Wombat Creek may be preserved in narrow fault slivers, with the Tongaro Sandstone having a more widespread distribution west of the Wombat Creek Fault, than is depicted in Fig. 1.

Age: Etheridge (in Ferguson 1899) examined fossils from the Wombat Creek Group and assigned them a Late Silurian age. Chapman (1920) suggested that some beds were Middle Devonian, while the remainder were "Yeringian", which was then considered to be Late Silurian. Talent (1960) re-examined Chapman's faunas and concluded that there was no evidence for a Devonian age. The age of the Group is presently considered to be Late Silurian (Ludlovian-Pridolian), although the Toaks Creek Conglomerate may even be as old as Llandoverian (Talent 1959a, 1965, Talent *et al.* 1975).

Toaks Creek Conglomerate

(New name, named after Toaks Creek, Benambra district)

Distribution, Type Section, Thickness: The Toaks Creek Conglomerate is a wedge shaped unit of massive conglomerate with subordinate sandstone, siltstone and pebbly mudstone which outcrops in the area from the Toaks Creek Track to the junction of the Mitta Mitta and Gibbo Rivers. The thickest section and best exposures of the Toaks Creek Conglomerate are along the Toaks Creek walking track between Limestone Gap and Toaks Creek in the northern part of the graben, and this is the proposed type section (GR 537363 to GR 553380). Its thickness is probably up to 2300 m. Good exposures along the Mitta Mitta River are now inundated by the waters of the Dartmouth Dam.

Lithology: The Toaks Creek Conglomerate is characterized by massive, clast-supported conglomerate consisting of well rounded pebbles, cobbles and occasional boulders of quartzite, vein quartz, black and green chert, rhyodacite, rare andesite, argillaceous and rare granitic clasts in a very coarse to fine sandy matrix. The clast composition becomes less variable towards the top of the unit where the conglomerate consists almost entirely of quartzite pebbles. Thin sandstone units consisting of common quartz as well as some vein quartz, chert and siltstone grains, are interbedded with conglomerates and have the same composition as the conglomerate matrix.

The conglomerates are massive and usually poorly bedded. Some thin beds grade upwards from lenticular pebble conglomerate to coarse and medium grained sandstone. Bedding thickness varies from 5 cm to several metres. Large conglomerate-filled channels with erosional bases into siltstone are recognizable along the spur between the Mitta Mitta and Gibbo Rivers. Elsewhere scour and fill structures, pebble imbrication and rare cross stratification are observed.

A thin unit of siltstone and feldsparthic sandstone occurs at the base of the Toaks Creek Conglomerate near Toaks Creek. This unit is continuous for several kilometres southwards to the Mitta Mitta-Gibbo River junction where it passes into interbedded conglomerate, sandstone, siltstone and pebbly mudstone up to 30 m thick. The pebbly mudstone contains sparsely scattered clasts, up to 0.5 m, of limestone, rhyodacite, vein quartz, chert and quartzite in a green grey structureless mudstone matrix. This unit wedges out and is faulted beneath the Mitta Mitta Volcanics along the Gibbo River. Thin discontinuous siltstone units are interbedded with conglomerate. They are structureless to laminated, grey-green in colour, locally partly silicified and consist of angular to subangular quartz with interstitial clays and chlorite. At the contact with the Mitta Mitta Volcanics the siltstones are strongly fractured.

Palaeontology and Age: Trimerellid brachiopods indicating a late Llandovery or younger Silurian age have been found in siltstones intercalated in the Toaks Creek Conglomerate (Talent 1959a, 1965, Talent *et al.* 1975). Rare reworked favositid corals have also been found. Chapman (1906) reported the long ranging *Atrypa reticularis* in the Toaks Creek Conglomerate. A lime-

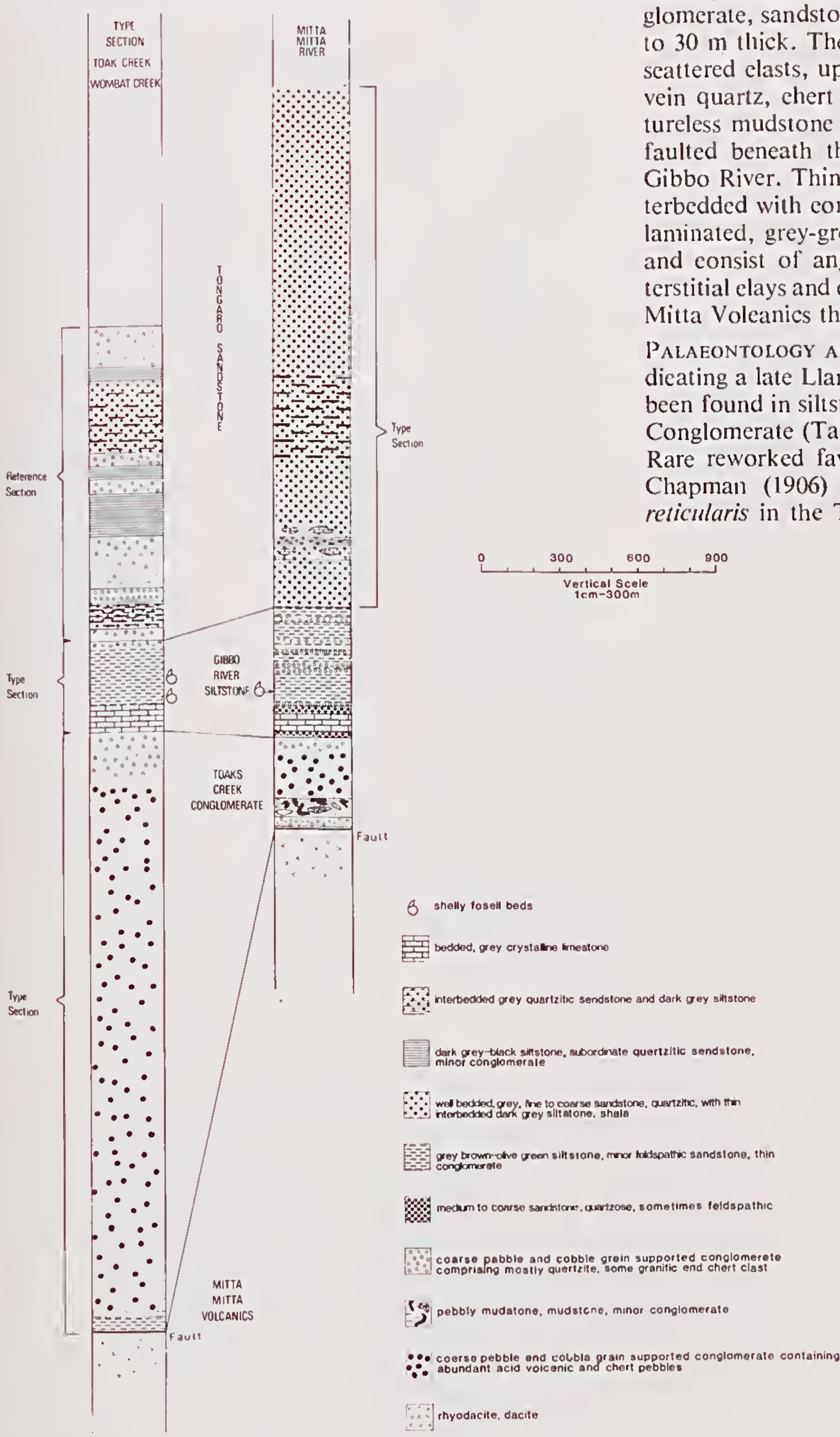


Fig. 2 — Columnar sections through the Wombat Creek Group.

stone clast in the pebbly mudstone unit at the Mitta Mitta-Gibbo River junction yielded a single simplexiform element of *Panderodus unicostatus* but this did not enable determination of an older age limit for the Toaks Creek Conglomerate (Cooper 1977).

Gibbo River Siltstone

(New name, named after Gibbo River, Benambra district)

DISTRIBUTION, TYPE SECTION, THICKNESS: The Gibbo River Siltstone is a thin unit of siltstone, calcareous siltstone, conglomerate, sandstone and, at the base, a number of limestone lenses. It is best exposed in its type section along the Limestone Gap Track, where it is 350 m thick (GR 542355 to GR 541352). In the Gibbo River area and the eastern flank of the Lower Tableland, its outcrop width is exaggerated by folding, but it is probably more than 700 m thick. Individual limestone lenses are up to 100 m thick (Whitelaw 1954).

LITHOLOGY: The dominant lithology is grey-green to buff coloured siltstone and calcareous siltstone, consisting of silt-sized angular-subangular quartz grains and some shell fragments in a clay-chlorite-mica matrix. Beds are generally massive, often bioturbated, with some planar lamination and rare small scale cross lamination and scour-and-fill structures. Near the Wombat Creek Fault, the siltstones possess a well developed slaty cleavage. Lenses of fossiliferous grey and white crystalline limestone occur at the base of the Gibbo River Siltstone and directly overlie the Toaks Creek Conglomerate in the western part of the Graben. A thin fossiliferous sandstone underlies the limestone, along the Mitta Mitta River. Eastwards along the Gibbo River, limestone lenses are enveloped by conglomerate and fossiliferous siltstone. The limestone lenses outcrop as broad mounds in the Limestone Gap-Quart Pot Flat area, but form vertical bluffs in the Mitta Mitta and Gibbo River exposures. They are planar bedded with beds up to 30 cm thick. The limestones are usually bioclastic (mostly corals, crinoids and brachiopods), and range from grainstones to packstones. Pelletal grains are abundant in limestone near Quart Pot Flat (GR 563332). The lens at Limestone Gap (GR 542355) contains angular irregularly shaped clasts of calcareous mudstone, and is strongly silicified and dolomitized. Recrystallized dolomitic limestone occurs at the hairpin bend of the Gibbo River (GR 608314). Coarse-grained marble with its original depositional texture completely obliterated outcrops near the mouth of Morass Creek.

Numerous thin conglomerates up to 10 m thick are interbedded with siltstones in the Morass Creek and Gibbo River areas. They contain well rounded quartzite and rare chert clasts. Along the Mitta Mitta River, the Gibbo River Siltstone becomes coarser grained near the top and comprises siltstone interbedded with graded and cross laminated fine to coarse quartz sandstone, a thin intraformational conglomerate, and a massive structureless cobble conglomerate, up to 25 m thick, contain-

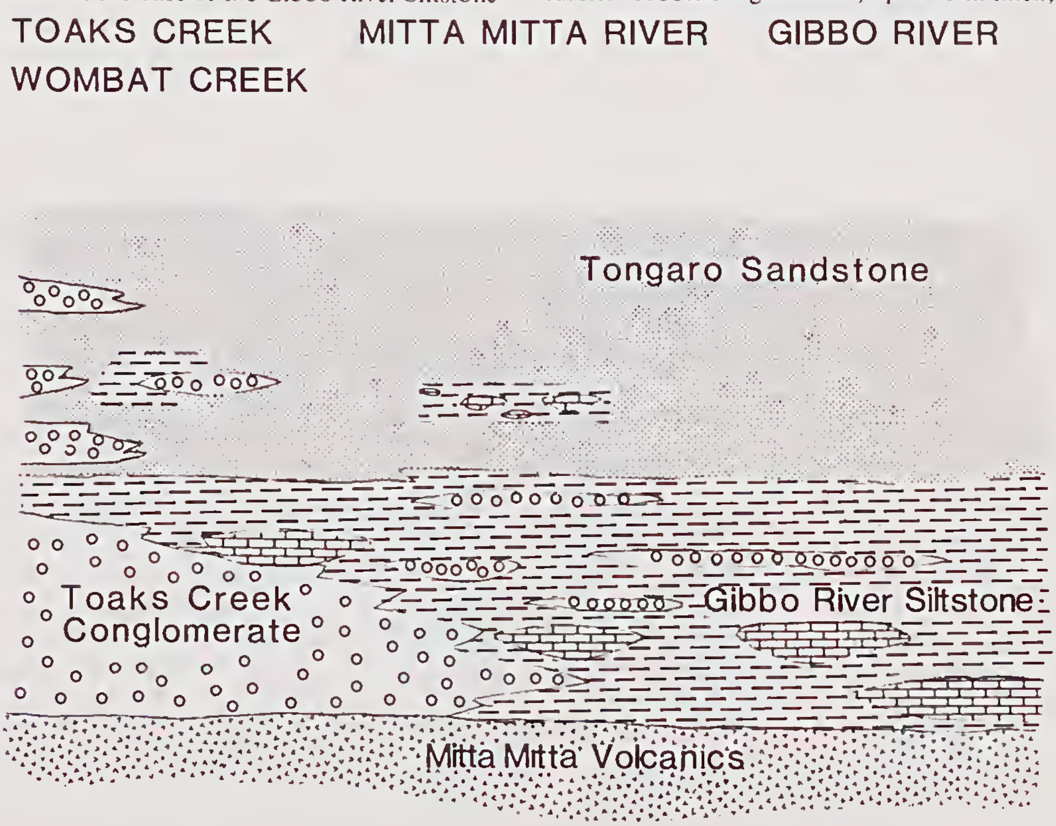


Fig. 3—Facies relationships of Silurian units within the Wombat Creek Graben.

ing mostly quartzite and some granitic clasts.

Relationships: The Gibbo River Siltstone conformably overlies the Toaks Creek Conglomerate along the Mitta Mitta River and in the Limestone Gap-Quart Pot Flat area, although in the Gibbo River area, the basal beds are laterally equivalent to parts of the Toaks Creek Conglomerate (Fig. 3). VandenBerg (1976) suggested that the limestones are allochthonous blocks contained in the upper units of the Toaks Creek Conglomerate. However, although the contacts with the surrounding rocks are not well exposed, the limestone lenses appear to be enclosed in fossiliferous, often calcareous siltstone of the Gibbo River Siltstone and are considered to be autochthonous.

The boundary with the overlying Tongaro Sandstone is sharp along Limestone Gap track, but along the Mitta Mitta River, the Gibbo River Siltstone is sandy towards the top and appears to grade into the Tongaro Sandstone.

Palaeontology and Age: The Gibbo River Siltstone contains a diverse fauna including brachiopods, crinoids, trilobites and corals in the siltstones, and corals, stromatoporoids, crinoids, brachiopods and rare conodonts in the limestone lenses. The fauna has not been examined in detail and awaits future study.

The siltstones contain species of *Isorthis, Platystrophia, Hesperorthis, Atrypoidea,* (?) *Pentamerus, Howellella* and *Nucleospira* (M. J. Garratt pers. comm. 1974) which suggest a Late Silurian (Ludlow) age. *Mucophyllum liliiforme, Propora conferta* and *Favosites allani* have been identified from limestones and indicate a Wenlock to Ludlow age (Talent 1959a, 1960, Talent *et al.* 1975). Cooper (1977) extracted elements of the conodonts *Ozarkodina excavata, Panderodus unicostatus,* and *Walliserodus* sp. but only a broad Early Silurian to Early Devonian age could be inferred from this collection.

Chapman (1906) described a species of a cephalaspid fish from siltstones in the formation, but this was later reidentified as a cast of a compound coral (Hills 1958).

Tongaro Sandstone

(New name, named after Parish of Tongaro)

Distribution, Type Section, Thickness: The Tongaro Sandstone, comprising sandstone, siltstone, conglomerate and limestone is the uppermost unit of the Wombat Creek Group and outcrops between the Limestone Gap Track and the Mitta Mitta River. The proposed type section on the Mitta Mitta River between GR 586312 and GR 588260 contains good exposures on the spurs overlooking the river. The thickness in this section is approximately 2000m and a sequence 1200 m thick is exposed in a reference section along Wombat Creek (between GR 547342 and GR 541336).

Lithology: The Tongaro Sandstone is characterized by well bedded quartzitic sandstone and interbedded grey to black siltstone. The sandstones are grey coloured, fine to medium grained quartz wackes (*sensu* Okada 1971) consisting of common quartz sand, rare muscovite, altered feldspar, chert and mudstone in a muddy matrix. Some sandstones have a bimodal framework consisting of well rounded coarse sand and angular fine sand grains. Beds are usually less than 30 cm thick with planar boundaries. Sedimentary structures include planar lamination, cross lamination and ripple marks. Graded units are rare. Lenses of well-bedded dark grey limestone up to 30 m thick (Whitelaw 1954) outcrop sporadically along the Mitta Mitta River and northwest towards Wombat Creek. They are planar bedded, with beds up to 50 cm thick. A fossiliferous packstone-wackestone exposed along the Mitta Mitta River is strongly foliated.

The Tongaro Sandstone varies laterally. In the northwest along Wombat Creek, quartz sandstone is less abundant than along the Mitta Mitta River, while thinly bedded dark grey to black siltstones increase in thickness. Massive, poorly bedded lenticular conglomerates, which wedge out southwards, form steep bluffs and strike ridges near Wombat Creek southwest of Limestone Gap. The conglomerates consist of randomly orientated, well rounded cobbles and pebbles of quartzite. Individual conglomerate lenses are up to 200 m thick.

A small outlier of the Wombat Creek Group is exposed along Morass Creek near Benambra township and is tentatively referred to the Tongaro Sandstone. It consists of a thin, poorly exposed grey limestone, known as Pyle's limestone deposit, slaty siltstone and quartzite pebble conglomerate. The limestone has been completely recrystallized and contact metamorphosed to skarn by the intrusion of the Triassic Mount Leinster Complex. Wollastonite is recognizable in thin section and Whitelaw (1954) reported the occurrence of garnet.

Relationships: The Tongaro Sandstone conformably overlies the Gibbo River Siltstone along the Mitta Mitta River. The base of the Tongaro is marked by the first plane bedded structureless quartzitic sandstone. The relationships are complicated by faulting and overturning along the Limestone Gap Track, although here the Tongaro Sandstone also appears to overlie the Gibbo River Siltstone. Along strike, the Tongaro grades laterally into the upper parts of the Gibbo River Siltstone. The top of the Tongaro Sandstone is faulted by the Wombat Creek Fault against graptolitic Upper Ordovician quartzite, sandstone and slate along Wombat Creek and along the Limestone Gap Track where there is a 50 m wide crush zone. Due to the lithological similarity with the Ordovician the faulted boundary is more difficult to locate between Wombat Creek and the Mitta Mitta River.

Palaeontology and Age: Apart from unidentifiable fragmentary shelly fossils in sandstones along the Limestone Gap Track, the non-calcareous part of the Tongaro Sandstone is unfossiliferous. Limestones outcropping along the Mitta Mitta River contain halysitid corals (Talent 1959a, 1965, Talent *et al.* 1975) and pentamerid brachiopods.

Conodonts recovered from limestone along the Mitta Mitta River include a single costate element of *Panderodus unicostatus*, which has ornament of a type only found in post-Wenlockian collections (Cooper 1977). The presence of halysitid corals indicates a Silurian age, thus confining the Tongaro sandstone in the Mitta Mitta River to the Late Silurian. Pyles limestone deposit near Benambra contains poorly preserved spiriferid brachiopods and conodonts including *Spathognathodus remscheidensis*?, *S. inclinatus inclinatus*, *Hindeodella priscilla* and *Neoprionodus* sp., which suggest a Pridolian or younger age (Bischoff, in Talent *et al.* 1975) for this deposit.

CORRELATION

The Mitta Mitta Volcanics and the Wombat Creek Group can be broadly correlated with other Silurian successions in southeastern Australia. The most similar sequence is exposed in the Indi River-Limestone Creek area east of Benambra, where the Silurian sequence comprises an acid volcanic unit, the Thorkidaan Volcanic Group, conformably overlain by the Enano Group, which consists of terrigenous and carbonate sediments with thin interlcalated volcanics (A. H. M. VandenBerg *et al.* in press). Tentative correlation between units in the Wombat Creek and Indi River successions (Table 1) is based more on lithological similarities than on palaeontological evidence, although the Gibbo River Siltstone at Wombat Creek and the Cowombat Siltstone along the Indi River contain similar faunas and are probably contemporaneous units (Talent 1959a).

Further east in the Yalmy area, possible equivalents to the Wombat Creek Group are the Sardine Beds (Talent *et al.* 1975) while Silurian sediments are known in bores near Nowa Nowa (Talent 1959a). A poorly known succession at Quidong north of Yalmy contains beds of similar age to the Wombat Creek Group (Talent *et al.* 1975).

Precise correlation with the better known succession at Yass in New South Wales is not possible although the regional stratigraphy suggests possible correlation of the Mitta Mitta Volcanics with the Hawkins Volcanics of the Douro Group, and the Gibbo River Siltstone is probably equivalent to parts of the Silverdale Formation and Black Bog Shale.

DISCUSSION OF THE WOMBAT CREEK GROUP

Depositional Environments

The Toaks Creek Conglomerate forms a wedge-shaped body in the northwest of the Wombat Creek Graben. Sedimentary structures include graded bedding, channels, rare cross-stratification and imbrication. The conglomerate has probably been deposited largely by traction currents although one pebbly mudstone unit near the base suggests mass movement. The Toaks Creek Conglomerate could be a type of "delta-fan" deposit accumulated at the margins of the marine basin. The occurrence of shelly fossils in interbedded mudstones indicates a marine origin for at least part of the Toaks Creek Conglomerate, but the possibility that part of the unit is of fluvial origin cannot be overlooked. The Gibbo River Siltstone comprises siltstone, limestone and thin conglomerate and sandstone. The lenticular limestones are mostly grainstones, and some packstones, cemented by ferroan calcite. They are interpreted to be carbonate buildups deposited under open shelf conditions. Siltstones for the most part are considered to be deposits settled from suspension onto a shelf inhabited by a diverse benthonic biota which has bioturbated the substrate. However they do contain rare sedimentary structures such as scour and fill structures, which suggest some current activity. The conglomerates in the Gibbo River Siltstone are massive, structureless closed framework deposits. Sandstones exposed near the top are graded, cross-laminated and associated with thin intra-formational conglomerate and show evidence of deposition by turbidity currents.

The Tongaro Sandstone in the Mitta Mitta River area consists of thin bedded quartz sandstone and interbedded dark siltstone enclosing small randomly distributed carbonate bodies. The sandstones contain few sedimentary structures, although small scale cross-stratification and planar lamination are observed. In the Wombat Creek area to the northwest the Tongaro Sandstone contains lenticular closed framework conglomerates. The conglomerates are interbedded with thinly bedded dark mudstone and thin, sometimes ripple marked, laminated and small scale cross-stratified quartz sandstone containing fragmented shelly fossils. Insufficient data are available to conclusively determine the depositional environment of the Tongaro Sandstone. The sandstones do not display well developed Bouma sequences. However, they are thin, laterally continuous and internally planar and cross-laminated, and resemble turbidites of Facies D and E described by Mutti and Ricci Lucchi (1978).

It is therefore suggested that the sandstones are mass-flow deposits. The association of turbiditic sandstones with conglomerates near Wombat Creek suggests that the conglomerates were deposited below wave base. It is not clear whether the limestone bodies along the Mitta Mitta River are allochthonous or were deposited *in situ*.

Nature and Origin of Terrigenous Detritus

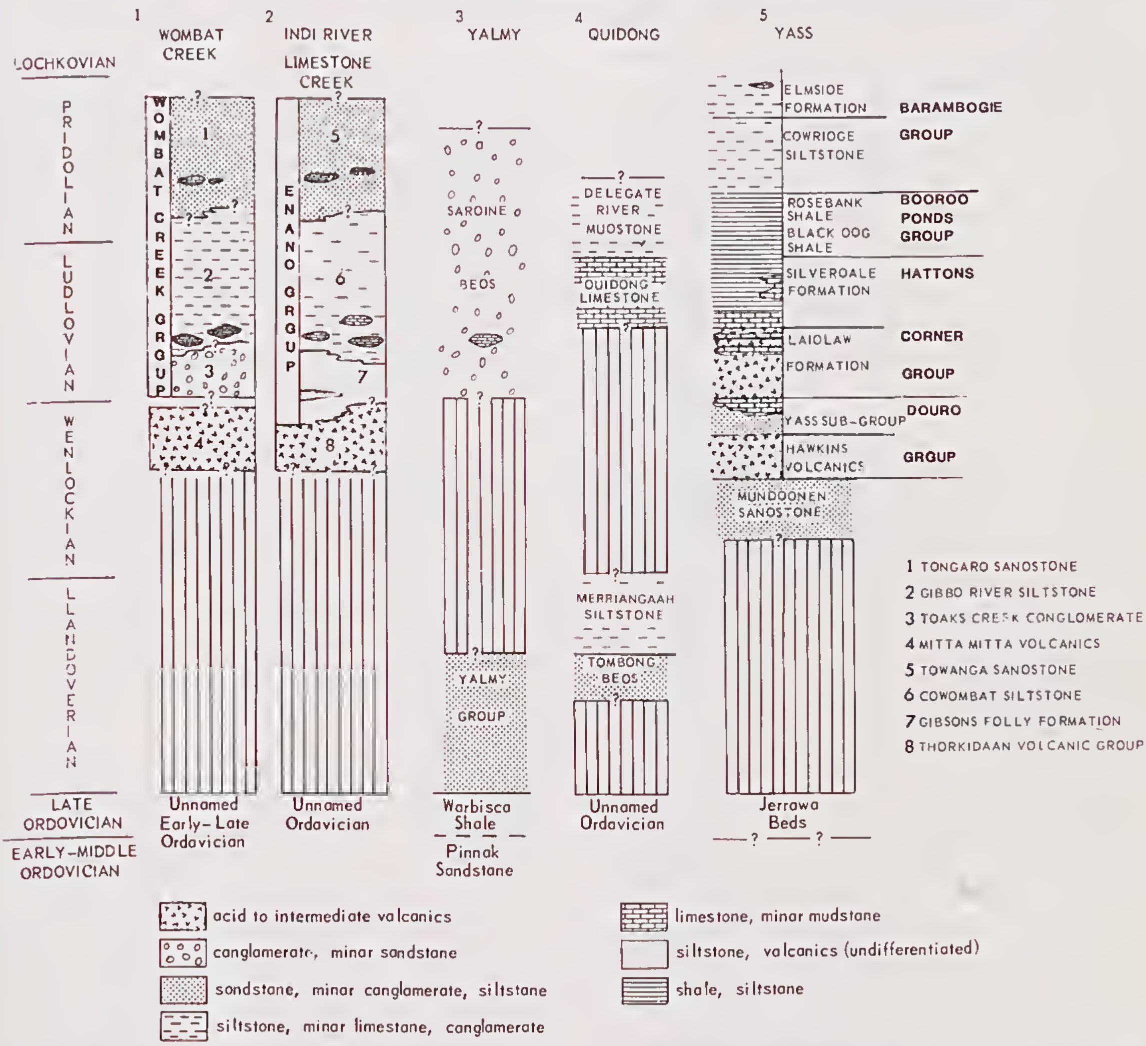
The basal Toaks Creek Conglomerate contains abundant pebbles of acid volcanic rocks derived from the underlying Mitta Mitta Volcanics. Towards the top of the unit the conglomerates become compositionally more mature and contain mostly quartzite and some chert pebbles.

The source of the quartzite clasts is uncertain, although clearly they are less muddy and less micaceous than the local Ordovician sandstones. Similarly chert, which is a major component of the Toaks Creek Conglomerate, is rare to absent in the Ordovician nearby. Argillaceous clasts in the Toaks Creek Conglomerate are not strongly foliated, although some have a weak fissil-

TABLE 1

CORRELATION OF WOMBAT CREEK GRABEN SEQUENCE WITH OTHER SILURIAN SEQUENCES IN SOUTHEASTERN AUSTRALIA.

1, Nomenclature this paper. 2, Nomenclature, VandenBerg *et al.* 1981. 3, Nomenclature, VandenBerg (unpubl.). 4, Nomenclature, Campbell in Talent *et al.* 1975. 5, Nomenclature, Pogson & Baker 1974.



ity, and no elasts of higher grade regional metamorphie rocks have been observed.

The Gibbo River Siltstone is eonsidered to be a transgressive faeies whieh has eovered the eoarse elastic wedge of the Toaks Creek Conglomerate with a thin eover of siltstone and limestone. Further offshore there was eontinued settling of silt and elay from suspension with intermittent influx of eoarse detritus transported into the basin by mass flows. It is in part laterally equivalent to the Toaks Creek Conglomerate, but represents a more offshore marine environment.

Towards the top of the Wombat Creek Group the coarse sediments become eompositionally mature, consisting almost entirely of quartzite and rare granitie clasts. Again the quartzite elasts are less muddy than the Ordovieian sandstones.

The quartzite elasts are petrographieally similar to quartzitic sandstones of the Lower Silurian Yalmy Group (A. H. M. VandenBerg pers. eomm.) which conformably overlies Upper Ordovieian graptolitie shales in the Yalmy area to the east. It is suggested that deposition in the Early Silurian may have eontinued as far west as the Wombat Creek Graben, covering the Ordovieian sediments. Following extrusion of the Mitta Mitta Volcanies, erosion of the voleanies oceurring outside the graben, as well as the Lower Silurian sediments and minor high level intrusions provided detritus to the subsiding basin. However, erosion did not proceed to suffieient depth to expose Ordovician beds or high grade regional metamorphic rocks.

STRUCTURAL RELATIONSHIPS BETWEEN ORDOVICIAN AND SILURIAN

Ordovician Structures

The most prominent structural element in the Ordovician is bedding which is folded into tight to isoclinal folds with steeply dipping to vertical axial surfaces. Isoclinal fold hinges have not been observed, but are inferred from changes of facing of beds. Major folds in the Ordovician trend between 120° and 200°, with the dominant direction NW-SE (Fig. 4a, b, c). Small scale, variably plunging folds, which may be minor folds on the flanks of major structures, are common in some areas and have an east-west trend. The folds are characterized by an axial plane slaty cleavage, defined by a preferred orientation of platy minerals and elongate quartz grains. The cleavage is strongly developed and penetrative in the slates, but is only weakly developed in the sandstones.

In thin section, a fissility defined by platy minerals aligned parallel to bedding can be seen to have been crenulated by the slaty cleavage. This earlier surface may be a folded slaty cleavage which is axial planar to an earlier set of folds, although no refolded folds have been observed in this area. However further north near Lockhart Gap, McKay (1969) has recorded mesoscopic folds refolded by northwest-trending regional structures. East-west trending folds which have been refolded by the northwest-southwest trending regional structures of the Omeo Metamorphic Complex have been recognized at Albury (Hellman 1976) and Tallandoon (Rogerson 1976). It thus appears that the Ordovician beds in northeastern Victoria have undergone at least two deformations.

Silurian Structures

The only prominent structural element observed throughout the Wombat Creek Group is Bedding. Beds

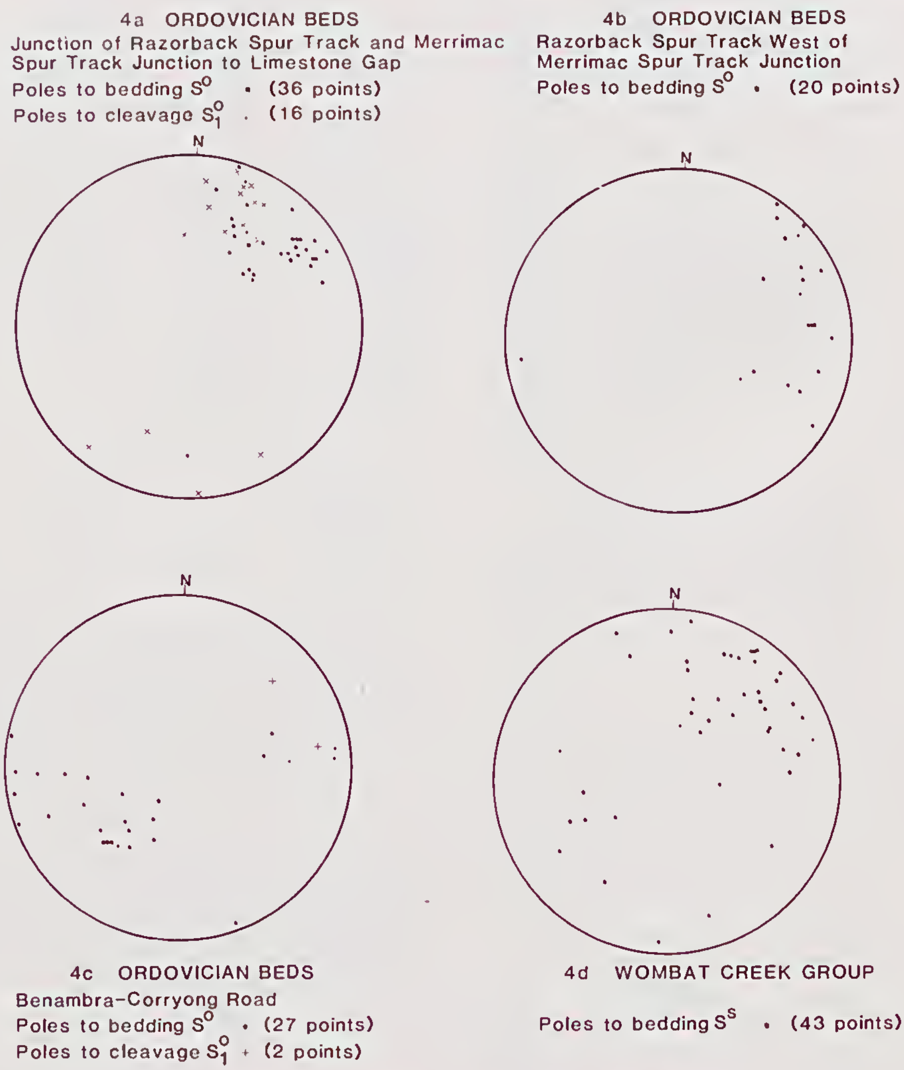


Fig. 4—Stereographic projections of bedding and cleavage surfaces.

are usually steeply dipping and sometimes overturned. No fold hinges have been observed, and the average fold trend of 150° is inferred from the direction and attitude of dips (Fig. 4d).

In contrast to the underlying Ordovician slates, strong foliation is only developed near major faults. There is a poorly defined reticulate cleavage in siltstones near the junction of the Mitta Mitta and Gibbo Rivers. Adjacent to the Wombat Creek Fault there is slaty cleavage in parts of the Gibbo River Siltstone and a prominent foliation, defined by stretched brachiopods, is parallel to bedding in a limestone lens of the Tongaro Sandstone on the east bank of the Mitta Mitta River.

Because of the near absence of bedding and the paucity of dipsin the Mitta Mitta Volcanics, the structure of this unit is not well known, but bedding trends are parallel with those of the Wombat Creek Group.

Discussion of the Benambran Deformation (or Mitta Mitta Movement)

The Benambra-Wombat Creek area is structurally significant in that it is the type area of the Benambran Orogeny (Browne 1947)—a tectonic event recorded from many localities through the Lachlan Fold Belt (e.g. Packham 1969, Crook *et al.* 1973). The deformation in the type area has been inferred from the structural differences between the Ordovician and Silurian beds (Talent 1959a). The Benambran Deformation was originally called the Mitta Mitta Movement by Andrews (1938, p. 151) but this name has failed to gain acceptance.

The contacts between the Ordovician and Silurian are always faulted and no angular unconformity has been observed. However the fold shapes and degree of deformation appear to differ between the Ordovician and Silurian in the study area. The variably plunging, tight, small scale folds in the Ordovician are not observed in the Silurian and the Ordovician probably has a refolded cleavage. In contrast, the continuity of marker beds in the Wombat Creek Group suggests tight but relatively simple folding in the Silurian rocks.

The metamorphic grade of the Ordovician in the Wombat Creek area is much higher than the Silurian, with the lowest grade (biotite zone) rocks passing westwards into the high temperature-low pressure Omeo Metamorphic Complex. Hellman (1976) has shown that the regional metamorphism at Albury post-dates early east-west trending folds but pre-dates northwest-southeast trending folds which are the prominent fold trends in the Omeo Metamorphic Complex. However, McKay (1969) and Rogerson (1976) suggested that metamorphic crystallization accompanied and post-dated the northwest-southeast folding.

The Omeo Metamorphic Complex is intruded by Early to Middle Silurian S-type granitic rocks with Rb/Sr ages of 430 ± 8 m.y. (Brooks & Leggo 1972, recalculated by J. Richards 1980 pers. comm.) and K/Ar ages from isolated granitic intrusions of 440 ± 9 m.y. (J. Richards pers. comm. 1980).

The Ordovician in northeastern Victoria has undergone at least two periods of folding with concomitant metamorphic and intrusive events. The folding and thermal events are here referred to as the Benambran Deformation, which has traditionally been considered to be Early Silurian in northeastern Victoria (Talent 1969, VandenBerg 1978).

In New South Wales, the Benambran Deformation is considered to range from the Early Silurian and comprise three separate tectonic events inferred from unconformities within the Silurian sequence at Orange (Packham 1969). The oldest of these, referred to as the Cobblers Creek Orogenic Phase, is of Late Ordovician to Llandovery age, while the Panuara Phase and the Quarry Creek Phase range from middle to late Llandovery and late Llandovery to Wenlock respectively. The tendency has been to correlate these events throughout the Lachlan Fold Belt (Scheibner 1973, Talent *et al.*, 1975), thereby assigning minor breaks in deposition and slight angular discordances to intense deformation events.

There is good evidence to infer that deformations took place between the Late Ordovician and Llandovery and the late Llandovery and the late Wenlock-Ludlow at a number of localities in southeastern New South Wales (Crook *et al.* 1973). The former event is referred to the Benambran Deformation and the latter to the Quidongan Deformation (Crook *et al.* 1973).

The age of the Benambran Deformation in its type area in northeastern Victoria is not closely constrained. The oldest possible age of the Toaks Creek Conglomerate, based on the occurrence of poorly preserved trimerellid brachiopods, is late Llandovery (Talent 1959a). However, tentative correlations with other areas in southeastern Australia (Table 1) suggest that the Mitta Mitta Volcanics and the Wombat Creek Group may be Middle and Late Silurian (Wenlock and Ludlow to Pridoli) respectively. If these "preferred" ages are accepted, there is a wide gap between deposition of graptolitic shales in the Late Ordovician and the extrusion of the Mitta Mitta Volcanics.

Evidence from east of the Wombat Creek Graben at Yalmy suggests that deposition was continuous during the Late Ordovician and Early Silurian (A. H. M. VandenBerg pers. comm.). It may have also extended westwards into the Wombat Creek Graben and the Indi River-Limestone Creek Graben. If so, the possibility that the Benambran Deformation is actually a late Early Silurian to Middle Silurian event cannot be precluded. The real Benambran Deformation in eastern Victoria may, in fact, be equivalent to the Wenlockian Quidongan Deformation, and events referred to the Benambran Deformation in southeastern New South Wales may be a pre-Benambran event not recognised in eastern Victoria.

SUMMARY

Turbiditic Early to Late Ordovician sandstone and shale suffered multiple deformation, high temperature-low pressure regional metamorphism and granitic intrusion during the Benambran Deformation. The resulting rocks comprise the Omeo Metamorphic complex.

The Wombat Creek Graben was initiated during or after the Benambran Deformation. In the Middle (?) to Late Silurian it was a locus for accumulation of a thick acid volcanic pile (the Mitta Mitta Volcanics) and subsequent fluvial (?) to shallow marine clastic and calcareous sediments (Toaks Creek Conglomerate and Gibbo River Siltstone) and turbiditic marine clastic sediments (Tongaro Sandstone). Clastic detritus was derived from the Mitta Mitta Volcanics extruded outside the graben, possibly from Lower Silurian clastic deposits and from the highest levels of the Omeo Metamorphic Complex. High grade rocks of the Metamorphic Complex were not exposed during the deposition of the Wombat Creek Group.

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